[redacted]

FACILITY FORM 602

N66-23843
(ACCESSION NUMBER)

(THRU)

73
(PAGES)

1
(CODE)

CR-71803
(NASA CR OR TMX OR AD NUMBER)

15
(CATEGORY)

GPO PRICE $ ____________

CFSTI PRICE(S) $ ____________

Hard copy (HC) 2.00

Microfiche (MF) .75

ff 653 July 65

SECTION 1

STUDY OF
WELDING EQUIPMENT FOR ELECTRONIC COMPONENTS

CONTRACT NAS 8-11488

SUMMARY

January 1966 LMSC/A626100

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

GEORGE C. MARSHALL SPACEFLIGHT CENTER

Huntsville, Alabama

Approved:

W. L. Palmer

W. L. Palmer
Project Leader

L. D. Brown

L. D. Brown, Manager
Manufacturing Research

FOREWORD

This report presents a general summary of the Lockheed Missiles & Space Company's Study of Welding Equipment for Electronic Components, performed for the National Aeronautics and Space Administration (NASA) under Contract NAS 8-11488 from the George C. Marshall Space Flight Center (MSFC).

LMSC Manufacturing Research Organization (48-10) personnel were responsible for Program Management.

The work was performed by the Process Development Group of Electronics Product Design (53-40) under the direction of Dr. Hans M. Wagner and Dale R. Torgeson.

The Material and Process Control Laboratory (48-50) provided testing, evaluation, and photomicrographic documentation services.

ABSTRACT

This report summarizes the results obtained during the LMSC Study of Welding Equipment for Electronic Components under NASA Contract NAS 8-11488 for the George C. Marshall Space Flight Center. During this investigation, four cross-wire welding machines and three parallel-gap welding machines were tested to determine their performance characteristics when used to bond selected material combinations. The complete contract report on these welding machines consists of a summary report and seven separately submitted section reports. (See p. iv.)

In addition to summarizing results for the entire contract effort, this section includes, to avoid repetition within each section report, discussions of information pertinent to the entire program, as follows:

- Selection and procurement of welding equipment.
- Selection of materials and material combinations to be welded.
- The two principal specifications for weldable leads (MSFC-SPEC-270A and MIL-STD-1276A). These specifications are compared, and the compliance of parent materials used in this study with these specifications is discussed.
- Details of cross-wire and parallel-gap welding electrodes.
- Development and certification of weld schedules by means of statistical methods.

The seven welding machines are rated, within their two respective groups, according to contractually established performance criteria. Recommendations are made for a subsequent study of additional machines.

REPORTING SYSTEM

Section		Report No. and Date
1	Study of Welding Equipment for Electronic Components – Summary	LMSC/A626100 – Jan 1966
2	GENERAL ELECTRIC Square-Pulse Bonder	LMSC/A775904 – Dec 1965
3	WELDMATIC Microbonder 1090C	LMSC/A759101 – July 1965
4	WELTEK AC-5/410-D	LMSC/A762532 – Aug 1965
5	SIPPICAN #4/214 DR	LMSC/A765535 – Sep 1965
6	RAYTHEON 225C/OB	LMSC/A767787 – Sep 1965
7	WELDMATIC 1-059-02/2-032-03	LMSC/A766194 – Oct 1965
8	WELDMATIC 1-065-02/2-032-03	LMSC/A776836 – Nov 1965

CONTENTS

ILLUSTRATIONS

TABLES

1.1 PURPOSE

Manufacturers of welding machines for welding electronic component leads and interconnecting materials in electronic modules are making rapid progress in developing their equipment. However, statements by these machine manufacturers regarding the quality of connections made by their particular equipment are sometimes conflicting. Also, the requirements of the machines for producing particular connections vary, depending upon the materials and configurations to be welded. Further, the wide and often uncontrolled variety of component lead materials which exist on the market today cause gross variations in the quality of the welded connections made.

The purpose of this study was to determine the performance characteristics of a selected number of commercially available welding machines when applied to welding different kinds of electronic circuitry. The results are intended to assist NASA-MFSC in establishing electronic welding requirements and specifications for circuitry presently being designed or investigated for Saturn space vehicles and future space programs.

1.2 WELDING MACHINES

1.2.1 SELECTION OF WELDERS

Welding machines for this study were selected both in consideration of the materials to be welded and in connection with the manufacturer's claims on machine performance. Since selection of the welders had to be made in mid-1964, the only models taken into account were those commercially available at that time. Ultrasonic, laser-beam, and electron-beam welders were not considered.

It was necessary to include welders for both cross-wire welding, with opposed or otherwise positioned electrodes, and welders with parallel-gap type electrodes. This provided resistance welding capabilities for the present state-of-the-art in materials used to build electronic circuit packages. However, several manufacturers produce welders which can be used alternately with opposed electrodes or with parallel-gap electrodes. It was therefore necessary to decide whether such welders should be included and studied for both applications. LMSC decided to use these dual-type welders only in the electrode arrangement for which they were originally designed; hence, each machine was studied under its most favorable performance conditions.

From a comprehensive review of available welders, LMSC chose seven welding machines for study and obtained NASA-MSFC approval for this selection.

Cross-Wire Welding. This group included the following machines:

- SIPPICAN Pincer-type Welder, Model 4/214DR
- RAYTHEON Microwelder, Model 225C/OB
- WELDMATIC Microwelder, Model 1-059-02/2-032-03
- WELDMATIC Microwelder, Model 1-065-02/2-032-03

These four welding machines were selected to enable comparison of the following features:

- Oil-filled capacitors vs. electrolytic capacitors
- Thyratron controlled discharge vs. solid-state controlled discharge
- Torsion-spring-actuated welding head vs. compression-spring-actuated welding head

Parallel-Gap Welding. This group included the following machines:

- GENERAL ELECTRIC Square-Pulse Bonder, Model CR 176B 1894 AA01
- WELDMATIC Microbonder, Model 1090C
- WELLS ELECTRONICS Weltek Microbonder, Model AC-5/410-D

The selection of the foregoing machines enabled the following features to be studied:

- Fixed gap vs. adjustable gap
- Capacitor discharge vs. d-c pulse vs. a-c pulse welding
- Weld heat-intercool time vs. pre-heat and post-heat

1.2.2 PROCUREMENT OF WELDERS

Purchase of all seven welders would have required an investment of $15,790 plus taxes, freight, and insurance. Since it could not be predicted which microwelders would be desired by NASA-MSFC after conclusion of this contract, a decision was made to lease each machine on a 3-month basis. The GENERAL ELECTRIC Square Pulse Bonder had already been purchased for use* on another NASA contract, and it was therefore available for this study.

---

*NASA Contract NAS 8-11475, Integrity of Electrical Connections.

A lease plan, as shown in Figure 1-1, was worked out with the various vendors so that each welder would be available to LMSC at a predetermined time for a period of 3 months. As the study progressed, several welding machines needed adjustments by the manufacturer, due to transportation damage or other reasons. The time required for these adjustments or repairs by the vendor was lost time for the contract. The respective vendors therefore agreed to extend the contractual lease periods to cover this lost time. All vendors concerned with this study were very cooperative and helpful in arranging for these extensions of leasing periods.

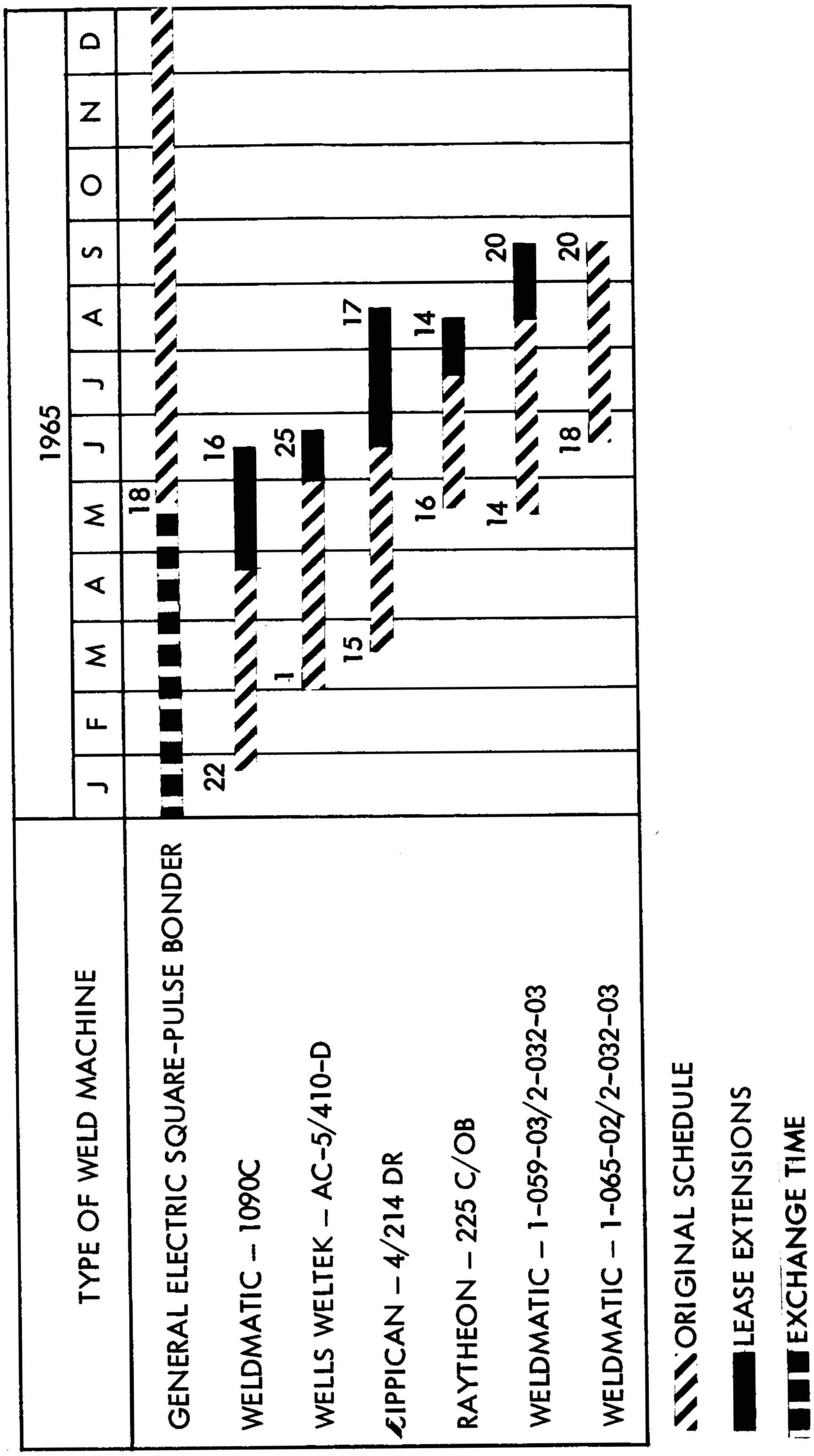


Fig. 1-1 Welding Machine Leasing Plan

1.3 TEST SPECIMENS

1.3.1 SELECTION OF MATERIALS

Two types of test specimen can be used to investigate welding machine performance and capability, namely:

- Specially selected test circuits welded on different machines and then tested for performance
- Individual weld specimens, welded on different machines and then tested mechanically and metallurgically in accordance with accepted procedures

Construction and evaluation of operational test circuits would still have required a basic evaluation of individual weld test specimens. Since this evaluation would have extended the time and cost of the program considerably, Lockheed decided to work only with individual weld test specimens.

The materials selected represent current circuit-building materials. The experience gained from evaluating all these test specimens can be used directly for welding any kind of circuitry containing such materials. Tables 1-1 and 1-2 show the materials used for parallel-gap and cross-wire welding, respectively.

1.3.2 PROCUREMENT OF MATERIALS

Cross-Wire Welding Materials. Vendor compliance with the Military Standard for Weldable Leads for Electronic Component Parts (MIL-STD-1276) and/or the MSFC Specification for Component Lead and Interconnection Materials for Welded Electronic Modules (MSFC-SPEC-270) presented recurring problems during LMSC procurement of materials for this welding study. In some cases, Lockheed received material which

Table 1-1

MATERIALS USED FOR PARALLEL-GAP WELDING

Material Combination	Welding Machine		
	GEN. ELEC. 176B	WELDMATIC 1090C	WELLS WELTEK
Pure Gold Wire			
0.001-in.			
to HALEX thin film on alumina	X		
Pure Gold Ribbon			
0.002 × 0.005-in.			
to 2,500 Å aluminum on glass		X	
to 6,000 Å aluminum on glass	X		
to HALEX thin film on alumina		X	X
to HALEX thin film on glass	X		X
to 0.003 × 0.018-in. nickel on epoxy fiberglas	X		
to 0.003 × 0.070-in. nickel on epoxy fiberglas	X		
0.003 × 0.010-in.			
to 6,000 Å aluminum on glass		X	
to gold-platinum thick film on alumina			X
to 0.003 × 0.094-in. nickel on epoxy fiberglas			X
to 0.003 × 0.070-in. T.I. Multilayer on epoxy fiberglas	X		
Kovar Ribbon, Gold-plated			
0.003 × 0.010-in.			
to 0.003 × 0.018-in. nickel on H-film	X		
to 0.003 × 0.070-in. nickel on H-film	X		
to 0.003 × 0.070-in. nickel on epoxy fiberglas	X		
to 0.003 × 0.094-in. nickel on epoxy fiberglas			X
to INTELLUX Multilayer board pad			X
T.I. Integrated Network Leads			
0.003 × 0.010-in. (Kovar, gold-plated)			
to 0.003 × 0.018-in. nickel on H-film	X		
to 0.003 × 0.018-in. nickel on epoxy fiberglas	X		
to 0.003 × 0.018-in. T.I. Multilayer on epoxy fiberglas	X		
Pure Nickel Ribbon			
0.002 × 0.005-in.			
to INTELLUX Multilayer board pad			X

Table 1-2

MATERIALS FOR CROSS-WIRE WELDING

Material Combination	Welding Machine			
	SIPPICAN 2/214 DR	RAYTHEON 225C/OB	WELDMATIC 1-059-02/ 2-032-03	WELDMATIC 1-065-02/ 2-032-03
Nickel Wire, Bare				
0.015-in.				
to 0.007 × 0.020-in. nickel ribbon, bare				X
0.020-in.				
to 0.020-in. nickel wire, bare	X			
to 0.032-in. nickel wire, bare			X	
to 0.010 × 0.031-in. nickel ribbon, bare			X	
to 0.020-in. Alloy 42 wire, gold-plated				X
to 0.016-in. Dumet wire, gold-plated		X		
to 0.025-in. Dumet wire, gold-plated			X	
to 0.017-in. Kovar wire, gold-plated	X			
to 0.025-in. OFHC copper wire, solder-coated				X
0.025-in.				
to 0.010 × 0.031-in. nickel ribbon, bare		X		
to 0.020-in. Dumet wire, gold-plated	X			
to 0.017-in. Kovar wire, gold-plated		X		
0.032-in.				
to 0.010 × 0.031-in. nickel ribbon, bare	X			
to 0.017-in. Kovar wire, gold-plated				X
Nickel Ribbon, Bare				
0.007 × 0.020-in.				
to 0.0126-in. Kovar wire, gold-plated			X	
0.010 × 0.031-in.				
to 0.020-in. Alloy 42 wire, gold-plated				X
to 0.020-in. Dumet wire, gold-plated				X
to 0.025-in. Dumet wire, gold-plated	X			
to 0.017-in Kovar wire, gold-plated	X			
to 0.020-in. Kovar wire, gold-plated	X			X
to 0.025-in. OFHC copper wire, solder-coated		X		

did not entirely conform to specification requirements. However, the extent to which these deviations affected weld quality was not investigated because LMSC considered this material to be representative of materials used throughout the Aerospace Industry.

The various cross-wire welding materials purchased for use on this contract were analyzed by the LMSC Materials and Process Control Laboratories to determine their compliance with the appropriate specifications. The results of such analysis are presented in Tables 1-3 through 1-6.

Table 1-3

ANALYSIS OF 0.010 × 0.003-INCH NICKEL RIBBON FOR COMPLIANCE WITH MIL-STD-1276, TYPE N-1

Chemical Analysis		
Element	Percentage Required Per Specification	Actual Percentage
Ni (+Co)	99.0 min.	99.515
Cu	0.25 max.	0.10
C	0.15 max.	0.071
S	0.01 max.	0.004
Fe	0.40 max.	0.07
Si	0.35 max.	0.08
Mn	0.35 max.	0.16
Mechanical Properties		
Property	Required	Actual
Elongation	25% in 1 inch min.	53%
Tensile Strength	82 ksi max.	69.4 ksi

Table 1-4

ANALYSIS OF 0.020-INCH NICKEL WIRE FOR COMPLIANCE WITH MIL-STD-1276, TYPE N-1

Chemical Analysis		
Element	Percentage Required per Specification	Actual Percentage
Ni (+Co)	99.0 min.	99.50
Cu	0.25 max.	0.03
C	0.15 max.	0.048
S	0.01 max.	0.003
Fe	0.40 max.	0.10
Si	0.35 max.	0.06
Mn	0.35 max.	0.26
Mechanical Properties		
Property	Required	Actual
Elongation	25% in 1 in. min.	23.0%*
Tensile Strength	82 ksi max.	82.8 ksi*

*Did not meet requirements of MIL-STD-1276

The following nickel materials were not analyzed because it was believed, on the basis of the wet analysis of the materials presented in Tables 1-3 and 1-4, that they constituted a fair sample of the nickel received:

- <u>Nickel Wire</u>

  0.015-in.

  0.025-in.

  0.032-in.

- <u>Nickel Ribbon</u>

  0.007 × 0.020-in.

Table 1-5

ANALYSIS OF 0.016-INCH DUMET WIRE (GOLD-PLATED)
FOR COMPLIANCE WITH MIL-STD-1276, TYPE D

Chemical Analysis of Core		
Element	Percentage Required per Specification	Actual Percentage
Ni	41 – 43	42.4
Fe	55 – 58	56.03
Mn	0.75 – 1.25	1.15
C	0.15 max.	0.115
Si	0.30 max.	0.19
S	0.02 max.	0.004
P	0.02 max.	0.013
Mechanical Properties		
Property	Required	Actual
Elongation	25% in 1 in. min.	47%
Tensile Strength	85 ksi max.	81.3 ksi
Finish		
Material	Required	Actual
Gold Plating	50 to 100 μin.	100 μin.
Nickel Under-plating	50 to 100 μin.	None

The weight of the completed core and sheath cross-section was 21.6% copper by weight; the Specification requires 18 to 26%.

The following Dumet wires were not analyzed because it was believed, on the basis of the wet analysis, that the material noted in Table 1-5 represented a fair sample of the Dumet received:

- 0.020-in.
- 0.025-in.

Table 1-6

ANALYSIS OF 0.017-INCH KOVAR WIRE (GOLD-PLATED)
FOR COMPLIANCE WITH MIL-STD-1276, TYPE K

Chemical Analysis		
Element	Percentage Required per Specification	Actual Percentage
Fe	53.0 nom.	53.12
Ni	29.0 nom.	29.19
Co	17.0 nom.	17.11
Mn	0.50 max.	0.30
C	0.06 max.	0.03
Si	0.20 max.	0.06
Al	0.10 max.	0.05
Mg	0.10 max.	nil
Zr	0.10 max.	nil
Ti	0.10 max.	0.012
Mechanical Properties		
Property	Required	Actual
Elongation	20% in 1 in. min.	32%
Tensile Strength	85 ksi max.	81.3 ksi
Finish		
Material	Required	Actual
Gold Plating	50 to 200 μin.	140 μin.

The following Kovar wires were not analyzed because it was believed, on the basis of the wet analysis, that the material noted in Table 1-6 represented a fair sample of the Kovar received:

- 0.0126-in.
- 0.020-in.

Alloy 42 (0.025-in., gold-plated) was purchased to comply with MSFC-SPEC-270, Type A. The chemical analysis was cancelled, however, because the wire was excessively out of conformance with the MSFC mechanical property specifications and appeared to be hard-drawn. The properties indicated were as follows:

Property	Required	Actual
Elongation	30% in 1 in. min.	2%
Tensile Strength	70 ksi min.	97.9 to 114 ksi

Parallel-Gap Welding Materials. Materials purchased for parallel-gap welding tests did not require compliance to a NASA or Military Specification. Vendor-supplied composition and thickness data for the following materials therefore were not verified by LMSC analysis:

- HALEX film traces on glass and alumina
- Vacuum evaporation-deposited aluminum on glass
- Nickel trace on DuPont "H" Film
- Texas Instrument Multilayer printed-circuit board on epoxy-filled fiberglas
- Nickel trace on epoxy-filled fiberglas
- INTELLUX Multilayer board with weldable (nickel) tabs
- Electra gold-platinum film on alumina (DuPont No. 7553 Platinum Gold paste fired at 1400°F to 1700°F)

The lead materials welded to the above circuitry, in cases other than pure gold, were spectroscopically analyzed. These materials included the following:

- Kovar leads on Texas Instrument integrated circuits
- Kovar ribbon, gold-plated
- Nickel ribbon

Tensile strength was determined on all lead materials except the Kovar leads on Texas Instruments integrated circuits. These strength values can be found in the appropriate section reports on the individual weld machine studies. This report and the section studies comprise a complete summary for this contract. (See Ref. 1-1.)

1.3.3 SPECIFICATIONS

Some of the difficulties encountered by LMSC in procuring the required materials for this study where previously mentioned (Subsection 1.3.2). Many lead material manufacturers have not converted their production to comply with Specifications MIL-STD-1276A or MSFC-SPEC-270A, except on a special order basis. It was therefore necessary, in several cases, to purchase material in manufacturing lot quantities because the material had to be especially prepared, e.g., drawn, annealed, plated, or otherwise treated.

The majority of materials were procured by specifying, as a requirement, compliance with Specification MIL-STD-1276, Leads, Weldable, for Electronic Component Parts, effective 14 Aug 1963. The superseding MIL-STD-1276A became effective 14 May 1965 after all materials for this study had been ordered and delivered.

Lockheed had first made strong efforts to procure materials in compliance with NASA Specification MSFC-SPEC-270, Component Lead and Interconnection Materials for Welded Electronic Modules. This specification was effective 20 May 1964, then revised as 270A on 19 Feb 1965. In most cases, however, vendors contacted tended to respond through adherence to MIL-STD-1276 rather than MSFC-SPEC-270.

The contents of both the NASA specification and the Military Standard were reviewed and compared during this study. The resulting chart (Table 1-7) compares specific callouts. Its analysis reveals the following noteworthy deviations:

- Alloy 42 is not covered in MIL-STD-1276A.
- Copper is not covered in MSFC-SPEC-270A.
- Gold-plating of leads is limited in MSFC-SPEC-270A to a minimum of 50 μin. and a maximum of 150 μin. MIL-STD-1276A establishes these limits at 50 and 200 μin., respectively. LMSC experience indicates that the lower range of 50 to 150 μin. called for in the NASA Specification is preferred for weldable leads.
- Nickel-plating thickness under the gold has a 20-μin. maximum specified by MSFC-SPEC-270A; MIL-STD-1276A allows a 50- to 100-μin. maximum for Dumet and a 20-μin. maximum for Kovar.

Table 1-7

WELDABLE LEADS FOR ELECTRONIC COMPONENT PARTS – COMPARISON OF MSFC-SPEC 270A AND MIL-STD-1276A

SPECIFIED PROPERTY	MSFC-SPEC-270A	MIL-STD-1276A
Title	Component Lead and Interconnection Materials for Welded Electronic Modules	Weldable Leads for Electronic Component Parts
Date of Issue	19 February 1965	14 May 1965
Applicable Documents	FED-STD-151: Metals, Test Methods	Same
	MIL-G-45204: Gold Plating (Electrodep.)	Same
	MSFC-STD-271: Fabrication of Welded Electronic Modules	–
Materials:		
Type A:	Yes	No
Type D:	Yes	Yes
Type K:	Yes	Yes
Type N:	Yes	Yes
Type C:	No	Yes

Table 1-7 (Cont.)

SPECIFIED PROPERTY	MSFC-SPEC-270A	MIL-STD-1276A
Dimensions:	As specified for each lead material	Inches / Millimeters 0.0120 ± 0.0010 / 0.30 ± 0.03 0.0160 ± 0.0010 / 0.41 ± 0.03 0.0200 ± 0.0015 / 0.51 ± 0.04 0.0250 ± 0.0020 / 0.64 ± 0.05 0.0320 ± 0.0020 / 0.81 ± 0.05 0.0400 ± 0.0020 / 1.02 ± 0.05 0.0040 ± 0.0008 / 0.10 ± 0.02 × 0.0120 ± 0.0010 / × 0.30 ± 0.03
Plating:	Gold plating in accordance with MIL-G-45204, Type I, Class 1. The composition shall be pure gold with no borates present when plated. Gold shall be a minimum of 50, and a maximum of 150 microinches thick. A nickel strike of 20 microinch maximum thickness is optional.	As specified for each lead material
Type A (Alloy 42)	Gold plated as specified above	Not included
Composition:	Minimum % (Weight) / Maximum % (Weight)	
Nickel	41.00 / 43.00	
Iron	55.00 / 58.00	
Manganese	0.75 / 1.25	
Carbon	– / 0.15	
Silicon	– / 0.30	
Sulphur	– / 0.02	
Phosphorus	– / 0.02	
Residuals	– / 1.00	

Table 1-7 (Cont.)

SPECIFIED PROPERTY	MSFC-SPEC-270A		MIL-STD-1276A	
Type A (Cont.)				
Temper:	Type A material shall be in the 1/4 hard condition		Not included	
Dimensions:	0.016 ± 0.001 inch 0.020 ± 0.001 inch 0.025 ± 0.001 inch 0.032 ± 0.001 inch		Not included	
Elongation:	30% minimum		Not included	
Tensile Strength:	70,000 psi minimum		Not included	
Resistivity:	425 (±10) ohms per circular mil foot at 20° C		Not included	
Type D (Dumet)				
Composition	Minimum % (Weight)	Maximum % (Weight)	Minimum % (Weight)	Maximum % (Weight)
Nickel-Iron Core:				
Nickel	41.00	43.00	41.00	43.00
Iron	55.00	58.00	55.00	58.00
Manganese	0.75	1.25	0.75	1.25
Carbon	–	0.15	–	0.15
Silicon	–	0.30	–	0.30
Sulphur	–	0.02	–	0.02
Phosphorus	–	0.02	–	0.02
Residuals	–	1.00	–	1.00

Table 1-7 (Cont.)

SPECIFIED PROPERTY	MSFC-SPEC-270A	MIL-STD-1276A
Type D (Cont.)		
Copper Sheath	99.9% minimum unborated copper with 0.006% maximum oxygen	99.9% minimum
Weight Copper	18 – 26 percent	Same
Gold Plating	As specified on page 1-17	The finished plating shall be gold with no borates present, in accordance with MIL-G-45204, Type I, Class 1. Minimum 50 microinches, maximum 200 microinches. Nickel underplating shall be minimum of 50 microinches and maximum of 100 microinches.
Temper	Core and sheath annealed and in the soft condition.	Same
Dimensions	0.016 ± 0.001 inch diam. 0.018 ± 0.001 inch diam. 0.020 ± 0.001 inch diam. 0.025 ± 0.001 inch diam. 0.032 ± 0.001 inch diam.	See page 1-17
Elongation	20% minimum	20% minimum
Tensile Strength	70,000 to 85,000 psi	85,000 psi maximum
Resistivity	60 (±10) ohms per circular mil foot at 20° C	Not specified

Table 1-7 (Cont.)

SPECIFIED PROPERTY	MSFC-SPEC-270A	MIL-STD-1276A
Type K (Kovar)		
Composition:	Percent (Weight)	Percent (Weight)
Iron	53.00 nominal	53 % nominal
Nickel	29.00 nominal	29 ± 1 %
Cobalt	17.00 nominal	17 ± 1 %
Manganese	0.60 maximum	0.60 % maximum
Silicon	0.20 maximum	0.20 % maximum
Aluminum	0.10 maximum	0.10 % maximum
Magnesium	0.10 maximum	0.10 % maximum
Zirconium	0.10 maximum	0.10 % maximum
Titanium	0.10 maximum	0.10 % maximum
Carbon	0.06 maximum	0.06 % maximum
	The combined total of Al, Mg, Zr, and Ti shall not be greater than 0.20%.	Combined total of aluminum, magnesium, zirconium, and titanium to be 0.20% maximum.
Gold Plating	As specified on page 1-17	Leads shall be goldplated in accordance with MIL-G-45204, Type I, Class 1. Gold shall be a minimum of 50 and a maximum of 200 microinches. Nickel underplating is optional, maximum thickness 20 microinches.
Temper	Bright annealed in a soft condition	Same
Dimensions	0.012 ± 0.001 inch diam. 0.017 ± 0.001 inch diam. 0.020 ± 0.001 inch diam. 0.004 by 0.012 ± 0.0005 inch 0.005 by 0.015 ± 0.0005 inch 0.006 by 0.018 ± 0.0005 inch 0.007 by 0.020 ± 0.0005 inch	See page 1-17

Table 1-7 (Cont.)

SPECIFIED PROPERTY	MSFC-SPEC-270A		MIL-STD-1276A
Type K (Cont.)			
Elongation	20 % minimum		20 % minimum
Tensile Strength	70, 000 to 85, 000 psi		85, 000 psi maximum
Resistivity	294 (± 5) ohms per circular mil foot, at 20° C		Not specified
Type N (Nickel	Bare wrought nickel		Type N-1 (Bare nickel)
Composition	Minimum % (Weight)	Maximum % (Weight)	Weight Percent
Nickel	99.00	–	99.00 minimum
Iron	–	0.400	0.40 maximum
Copper	–	0.250	0.25 maximum
Carbon	–	0.150	0.15 maximum
Manganese	–	0.350	0.35 maximum
Sulphur	–	0.008	0.01 maximum
Silicon	–	0.350	0.35 maximum
Titanium	–	0.020	—
Gold Plating	Optional; thickness minimum of 50 and maximum of 100 microinches		See below under Type N-2
Dimensions	0.016 ± 0.0005 inch diam. 0.020 ± 0.0005 inch diam. 0.025 ± 0.0005 inch diam. 0.032 ± 0.001 inch diam. 0.003 ± 0.0005 by 0.010 ± 0.001 inch 0.007 ± 0.0005 by 0.030 ± 0.001 inch 0.010 ± 0.0007 by 0.020 ± 0.001 inch 0.010 ± 0.0007 by 0.030 ± 0.001 inch 0.012 ± 0.0007 by 0.030 ± 0.001 inch		See page 1-17

Table 1-7 (Cont.)

SPECIFIED PROPERTY	MSFC-SPEC-270A	MIL-STD-1276A
Type N (Cont.)		
Elongation	25% minimum	20% minimum
Tensile Strength	72,000 to 82,000 psi	82,000 psi maximum
Resistivity	65 (± 5) ohms per circular mil foot at 50° C	Not specified
		Type N-2 (goldplated)
Composition		As Type N-1 above
Gold Plating		Gold plating shall be in accordance with MIL-G-45204, Type I, Class 1. Thickness from 50 to 200 microinches.
Dimensions	Not specified	See page 1-17
Elongation	Not specified	As Type N-1
Tensile Strength	Not specified	As Type N-1
Type C (Copper)	Not specified	Type C leads consist of tin-lead coated copper wire having the following chemical composition and plating:
Composition	Not specified	
Copper + silver trace		99.900 percent minimum
Oxygen		0.015 percent maximum
Silver		0.052 percent maximum
Phosphorus		0.015 percent maximum
Total of all impurities		0.100 percent maximum

Table 1-7 (Cont.)

SPECIFIED PROPERTY	MSFC-SPEC-270A	MIL-STD-1276A
Type C (Cont.)		
Tin-lead coating:		
Commercially pure tin or	Not specified	0.0001 inch average minimum 0.0006 inch average maximum
Tin Lead		10 – 70 percent 90 – 30 percent
		0.0001 inch average minimum 0.0010 inch average maximum
Dimensions	Not specified	See page 1-17
Identification	Type of material and plating wire diameter or ribbon dimension Lot number Date of manufacture Name of manufacturer	Not specified
Quality Assurance Provisions	See original SPEC.	None specified

1.4 WELDING OPERATIONS

1.4.1 ELECTRODES AND ACCESSORY TOOLING FOR CROSS-WIRE WELDING

Except for the SIPPICAN welding machine, electrodes and electrode holders for the cross-wire welding machines consisted of standard Lockheed tools. The specifications for these tools were established by standard tool engineers for use by LMSC Manufacturing.

Figure 1-2 shows the shape and dimensions of electrodes used with the RAYTHEON (Model OB) and WELDMATIC (Model 02-032-03) welding heads. The pertinent electrode holders are shown in Figure 1-3.

The electrodes used on the SIPPICAN welder (Model 4/214DR) are shown in Figure 1-4. The electrode holders are an integral part of the welding head and its special torque mechanism.

The styles of electrodes illustrated in Figures 1-2, 1-3, and 1-4 are available in all RWMA materials. However, LMSC used only RWMA No. 1 and 2 electrodes for this study.

1.4.2 ELECTRODES AND ACCESSORY TOOLING FOR PARALLEL-GAP WELDING

Parallel-gap welding electrodes and electrode holders are designed to meet the special requirements of this technique. No standard electrodes have been developed to date which can be used on all types of machines.

The GENERAL ELECTRIC Square-Pulse Bonder electrodes are stamped from sheet metal and then fastened together by means of a special inorganic insulating material,

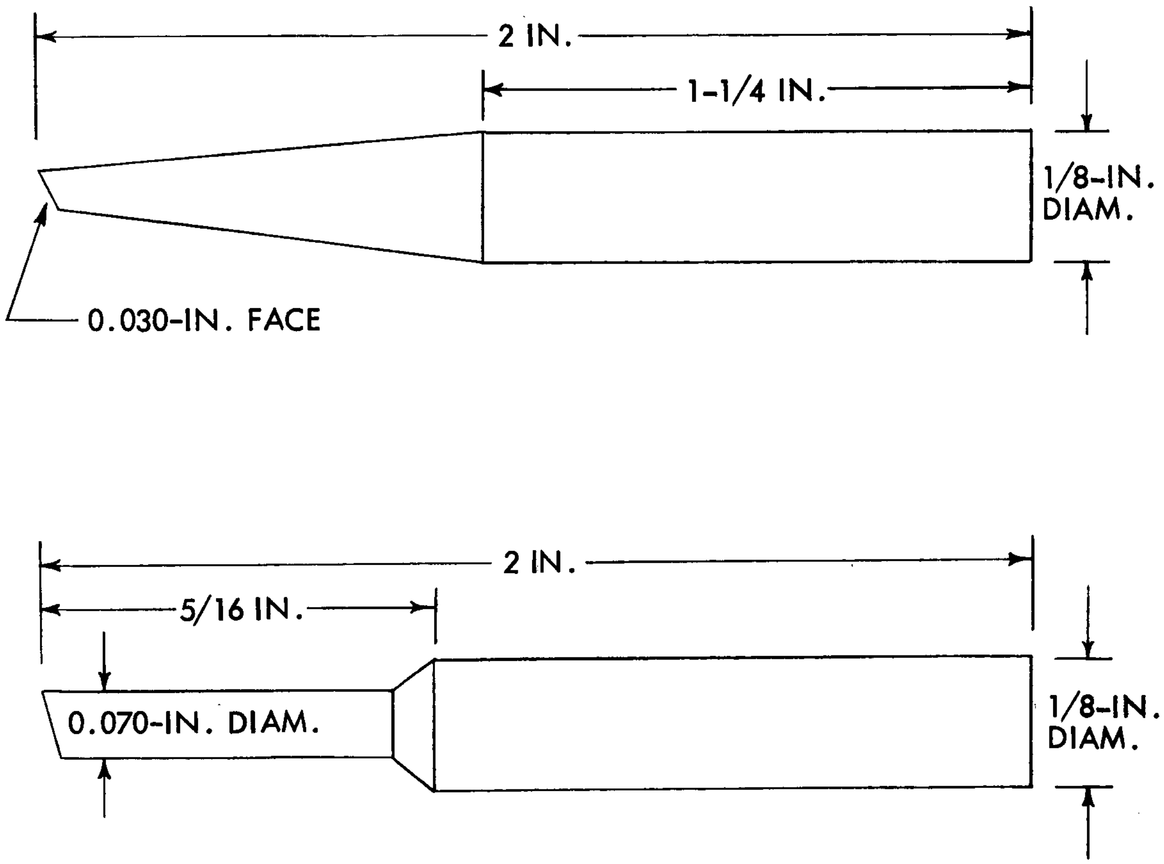


Fig. 1-2 Electrodes Used With RAYTHEON Model OB and WELDMATIC Model 02-032-03 Welding Heads

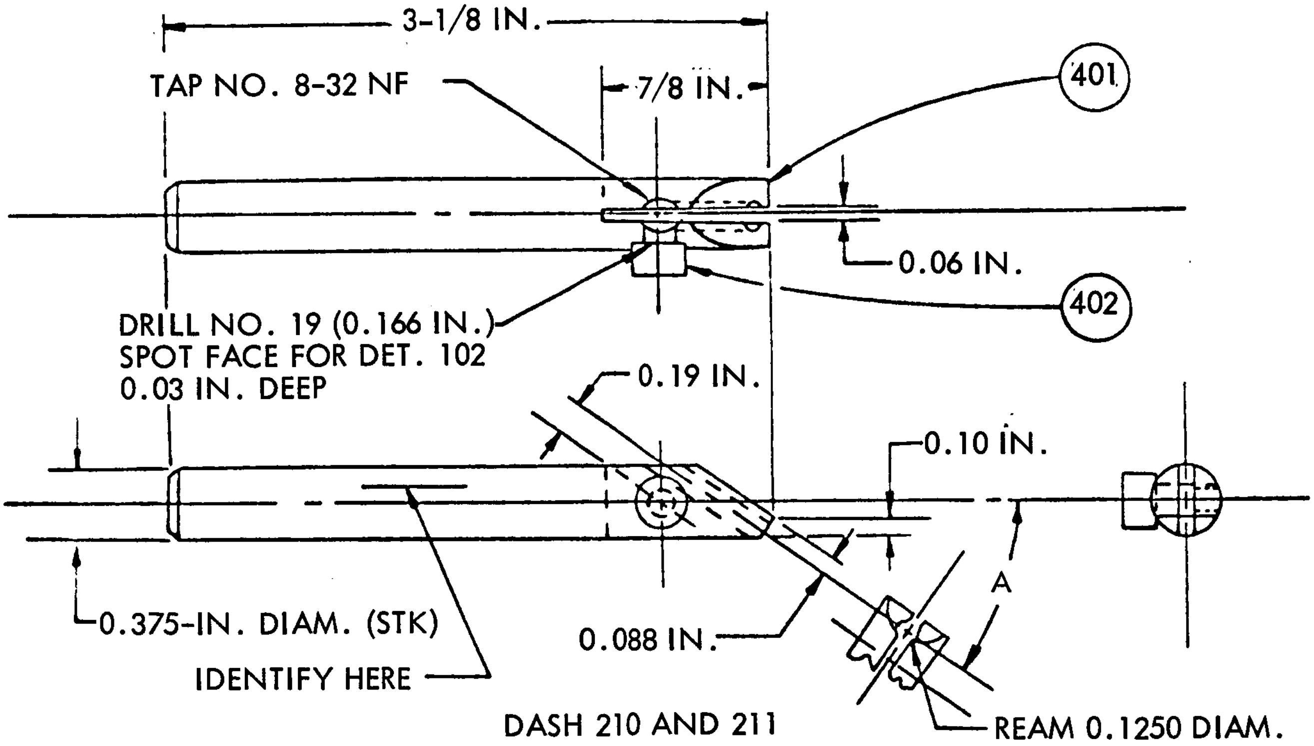


Fig. 1-3 Electrode Holder Used With RAYTHEON Model OB and WELDMATIC Model 02-032-03 Welding Heads

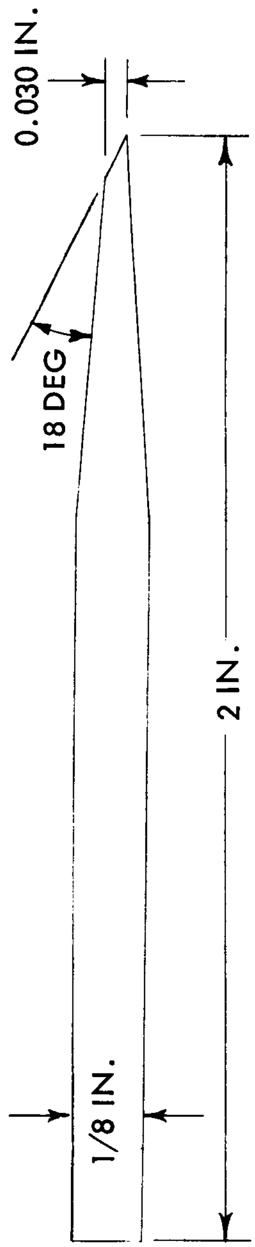
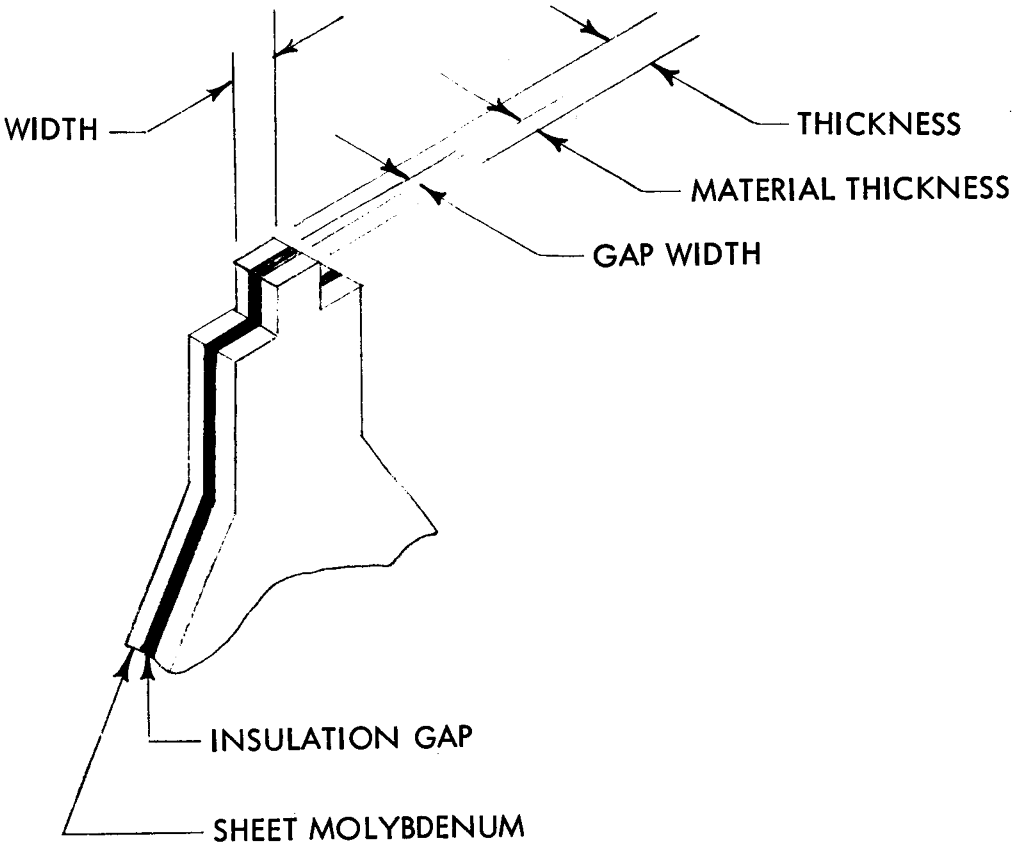


Fig. 1-4 SIPPICAN M3-700, 36-Deg Electrode (RWMA-2)

of which the composition is proprietary to General Electric Company (G. E.). The electrode materials used were molybdenum and RWMA No. 2. A schematic of the G. E. parallel-gap electrode is shown in Figure 1-5. Each electrode has two sets of tips, one on each end. This makes it possible to use the second set after the first is worn out (Ref. 1-2). The G. E. electrode holder is an integral part of the welding head. To change from one set of electrode tips to the other requires approximately 1 min. This time includes correct alignment of the parallel-gap electrode. Complete electrode replacement takes about 2 min.

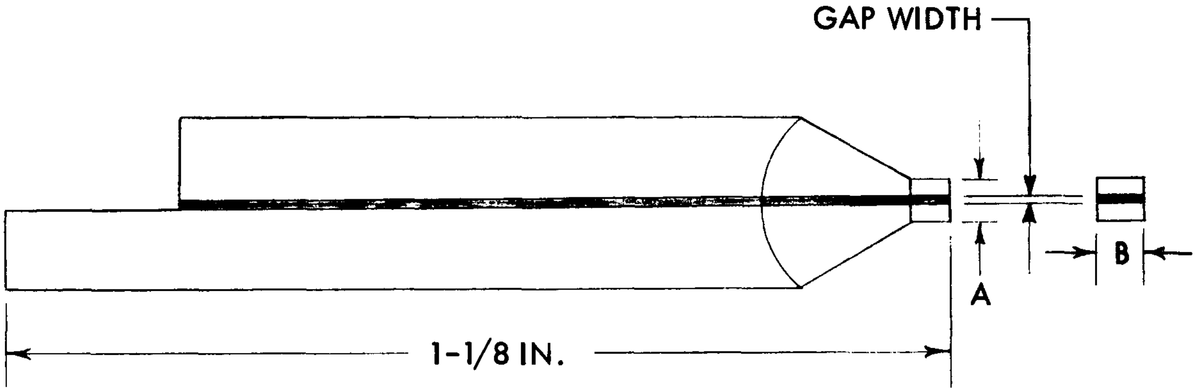
The WELDMATIC Microbonder (Model 1090C) parallel-gap electrode consists of two half-cylinders of electrode material bonded together by a flat strip of insulator, of which the thickness determines the gap width. The diameter of this split cylinder is reduced at one end and terminates in the actual welding tip as shown in Figure 1-6. Electrode material used for this study was molybdenum. The electrode holder is directly attached to the moving arm of the welding head (Ref. 1-3). A photomicrograph of the welding tip is shown in Ref. 1-4.

The WELLS WELTEK Microbonder, Model AC-5/410D, uses two individual electrodes with square tips separated by an adjustable air gap. Electrode materials used for this study were molybdenum and RWMA No. 2. Figure 1-7 shows the design of these electrodes which represents a modification of the cross-wire welding electrodes previously described in Subsection 1.4.1. This design makes it difficult to use very small gaps. Each of the two electrodes is held by an individual holder which is part of a separate welding head, as shown in Ref. 1-5.



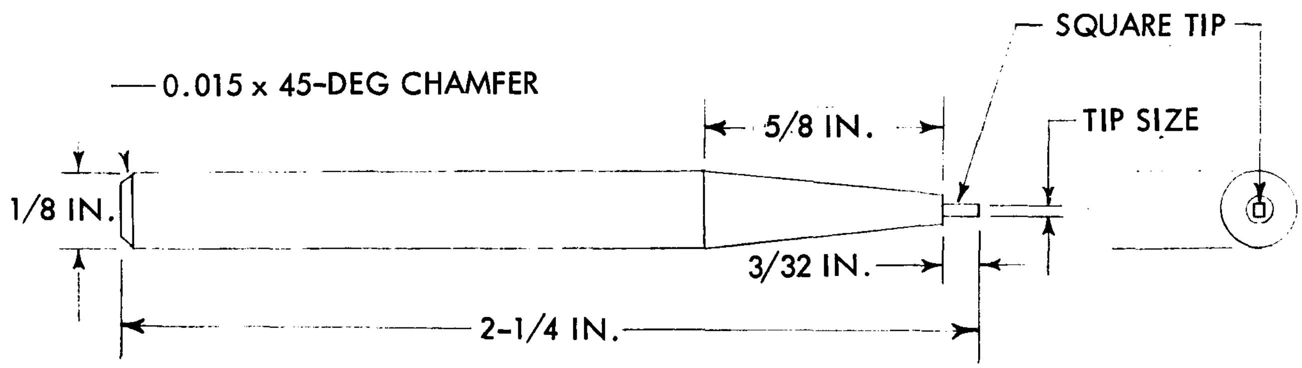
MATERIAL	TIP SIZE		GAP WIDTH	MFR. PART NO.
	WIDTH	MAT. THICKNESS		
MOLYBDENUM	0.020	0.005	0.006	106 AB
RWMA 2	0.020	0.005	0.006	108 AB
MOLYBDENUM	0.020	0.008	0.010	146 AB
RWMA 2	0.020	0.008	0.010	148 AB

Fig. 1-5 GENERAL ELECTRIC Square-Pulse Bonder Electrode



MATERIAL	TIP SIZES	GAP WIDTH	MFR. PART NO.
MOLYBDENUM	A × B: 0.020-IN. x 0.020-IN.	0.004	EM-1002

Fig. 1-6 Split Electrode – WELDMATIC, Model 1090C



TIP SIZE (IN.)	MATERIAL	COLOR CODE	WELTEK PART NO.
0.010 x 0.010	MOLYBDENUM	YELLOW	2W-006-071-B14
0.010 x 0.025	RWMA 2	RED	2W-006-071-A2
0.010 x 0.025	MOLYBDENUM	YELLOW	2W-006-071-B14

Fig. 1-7 WELTEK Electrode – Style 07

1.4.3 OPERATOR PERSONNEL AND TRAINING

All welding under this contract was performed by a welding machine operator trained and certified for production welding by the LMSC Education and Training Department. It should be noted that microwelding by means of gap-weld techniques is not presently covered by LMSC training and certification procedures. However, the operator selected for this work, though typical of production-line operators, was one who had previously performed laboratory work in module welding. The additional skills necessary for the gap-welding required in microcircuitry were therefore readily acquired.

A training program in microelectronic welding should be conducted in order to permit realistic evaluation of the "operator variable" during the performance of studies in this area. This is particularly important at this time when machines with a wide range of complexity and sophistication are becoming available.

1.5 DEVELOPMENT OF WELD SCHEDULES

1.5.1 CROSS-WIRE WELDING

The criteria for evaluating an electronic welding joint for quality and reliability are, in principle, the same as those long established for welding in general. These criteria include the following:

- Adequate strength – equal to or exceeding that of the parent materials themselves
- Absence of non-ductile intermetallics
- Freedom from voids, inclusions, notches, cracks, etc.

The mechanical strength of the welded joint is achieved by fusion and/or diffusion to form an alloy of the constituents welded. In electronic welding, the desired or minimal mechanical properties must be achieved in the as-welded condition. This is because there is no possibility of subsequent heat treatment or mechanical work treatment by which these properties may be modified or improved.

The method of developing a weld schedule for joining two typical materials will be illustrated by using as examples the schedules developed for the following materials and machines:

- 0.020-in. nickel wire to 0.017-in. Kovar wire, using the SIPPICAN welder (Ref. 1-6)
- 0.025-in. nickel wire to 0.010 × 0.031-in. nickel ribbon, using the RAYTHEON welder, Model 225C (Ref. 1-7)

A preliminary weld schedule development sheet for welding 0.020-in. nickel wire to 0.017-in. Kovar wire, using the SIPPICAN welder, is shown in Figure 1-8. This figure shows the 26 points investigated. These data constitute the basis for constructing a conventional iso-strength diagram. Actually, the diagram was never constructed because the selection of a center point depended largely upon metallurgical considerations. The procedure was to select a point which (1) exhibited adequate mechanical strength, and (2) was surrounded by points which showed equal or adequate mechanical strengths and acceptable metallurgical conditions at the weld interface. In this case, on the basis of data shown in the table, a tentative center point was chosen at 3 watt-sec of weld energy and 4 lb electrode pressure. This selection appeared to be satisfactory with respect to both electrode pressure and weld energy (Ref. 1-8) and therefore formed the basis of the weld schedule for this material combination.

The following alternate method of selecting a center point from preliminary data has also been employed in several weld schedules developed for this study:

- Determine the average of the individual weld strengths $\bar{x}$.
- Calculate the standard deviation σ as follows:

$$\sigma = \sqrt{\frac{\sum (x - \bar{x})^2}{n - 1}}$$

where

x = strength of an individual weld (lb)

$\bar{x}$ = average strength of weld (lb)

n = total number of welds

WELDER: SIPPICAN, MODEL 2/214 DR DATE: 26 MARCH 1965

MATERIAL: 0.020-IN. NICKEL WIRE TO 0.017-IN. KOVAR WIRE

ELECTRODE PRESSURE (LB)	2	2.5	3	3.5	4	4.5
5	$\bar{x}$ = 15.35 σ = 1.68 $\frac{10\sigma}{\bar{x}}$ = 1.10	$\bar{x}$ = 17.71 σ = 1.84 $\frac{10\sigma}{\bar{x}}$ = 1.04	$\bar{x}$ = 23.77 σ = 0.394 $\frac{10\sigma}{\bar{x}}$ = 0.17	$\bar{x}$ = 23.50 σ = 1.04 $\frac{10\sigma}{\bar{x}}$ = 0.44	$\bar{x}$ = 23.63 σ = 1.04 $\frac{10\sigma}{\bar{x}}$ = 0.44	
4.5	$\bar{x}$ = 14.07 σ = 0.838 $\frac{10\sigma}{\bar{x}}$ = 0.59	$\bar{x}$ = 20.14 σ = 0.945 $\frac{10\sigma}{\bar{x}}$ = 0.47	$\bar{x}$ = 24.14 σ = 0.802 $\frac{10\sigma}{\bar{x}}$ = 0.33	$\bar{x}$ = 24.57 σ = 0.783 $\frac{10\sigma}{\bar{x}}$ = 0.32	$\bar{x}$ = 23.57 σ = 0.932 $\frac{10\sigma}{\bar{x}}$ = 0.40	
4.0	$\bar{x}$ = 13.57 σ = 1.97 $\frac{10\sigma}{\bar{x}}$ = 1.46	$\bar{x}$ = 18.07 σ = 1.79 $\frac{10\sigma}{\bar{x}}$ = 0.99	$\bar{x}$ = 23.07 σ = 1.45 $\frac{10\sigma}{\bar{x}}$ = 0.63	$\bar{x}$ = 23.71 σ = 1.21 $\frac{10\sigma}{\bar{x}}$ = 0.51	$\bar{x}$ = 23.85 σ = 0.748 $\frac{10\sigma}{\bar{x}}$ = 0.31	
3.5	$\bar{x}$ = 12.71 σ = 2.24 $\frac{10\sigma}{\bar{x}}$ = 1.76	$\bar{x}$ = 18.35 σ = 2.08 $\frac{10\sigma}{\bar{x}}$ = 1.14	$\bar{x}$ = 23.00 σ = 0.913 $\frac{10\sigma}{\bar{x}}$ = 0.39	$\bar{x}$ = 24.00 σ = 0.577 $\frac{10\sigma}{\bar{x}}$ = 0.24	$\bar{x}$ = 24.07 σ = 0.733 $\frac{10\sigma}{\bar{x}}$ = 0.30	$\bar{x}$ = 24.35 σ = 1.25 $\frac{10\sigma}{\bar{x}}$ = 0.51
3	$\bar{x}$ = 14.35 σ = 0.557 $\frac{10\sigma}{\bar{x}}$ = 0.39	$\bar{x}$ = 17.00 σ = 2.0 $\frac{10\sigma}{\bar{x}}$ = 1.18	$\bar{x}$ = 20.50 σ = 3.27 $\frac{10\sigma}{\bar{x}}$ = 1.59	$\bar{x}$ = 24.57 σ = 0.567 $\frac{10\sigma}{\bar{x}}$ = 0.23	$\bar{x}$ = 21.00 σ = 3.18 $\frac{10\sigma}{\bar{x}}$ = 1.51	

WELD ENERGY (WATT-SEC)

$\bar{x}$ Average pull strength
σ Standard deviation

Fig. 1-8 Preliminary Weld Schedule Development Data — 0.020-In. Nickel to 0.017-In. Kovar (SIPPICAN Welder)

- Plot the quantity $\frac{10\sigma}{\bar{x}}$ vs. weld energy for each pressure (lb) setting. (See Figure 1-9.)
- Plot the quantity $\frac{10\sigma}{\bar{x}}$ vs. weld pressure for each energy (watt-sec) setting. (See Figure 1-10.)
- Select from these plots the best value of electrode pressure and weld energy to minimize the $\frac{10\sigma}{\bar{x}}$ parameter.

An examination of the curves in Figures 1-9 and 1-10 indicates an electrode pressure of 3.9 to 4 lb and a weld energy of 3 to 3.5 watt-sec. The point selected for preliminary metallographic examination was 3 watt-sec at 4-lb pressure.

The preliminary weld schedule development sheet for welding 0.025-in. nickel wire to 0.010 × 0.031-in. nickel ribbon, using the RAYTHEON welder, is shown in Figure 1-11. This figure details the results of investigating 30 points, and the data constitute the basis of constructing the iso-strength diagram. From these data, a first trial center point for metallographic examination was selected at 20 watt-sec weld energy and 10-lb electrode pressure. The metallographic analysis indicated that this selection of electrode pressure and weld energy was satisfactory (Ref. 1-9).

Figures 1-12 and 1-13 are, respectively, plots of the quantity $\frac{10\sigma}{\bar{x}}$ vs. weld energy and $\frac{10\sigma}{\bar{x}}$ vs. electrode force. These curves tend to indicate that a minimal $\frac{10\sigma}{\bar{x}}$ would occur as follows:

- From Figure 1-12 at an electrode force of approximately 9 lb and 21 watt-sec weld energy
- From Figure 1-13 at approximately 9 lb of electrode force and 24 watt-sec weld energy

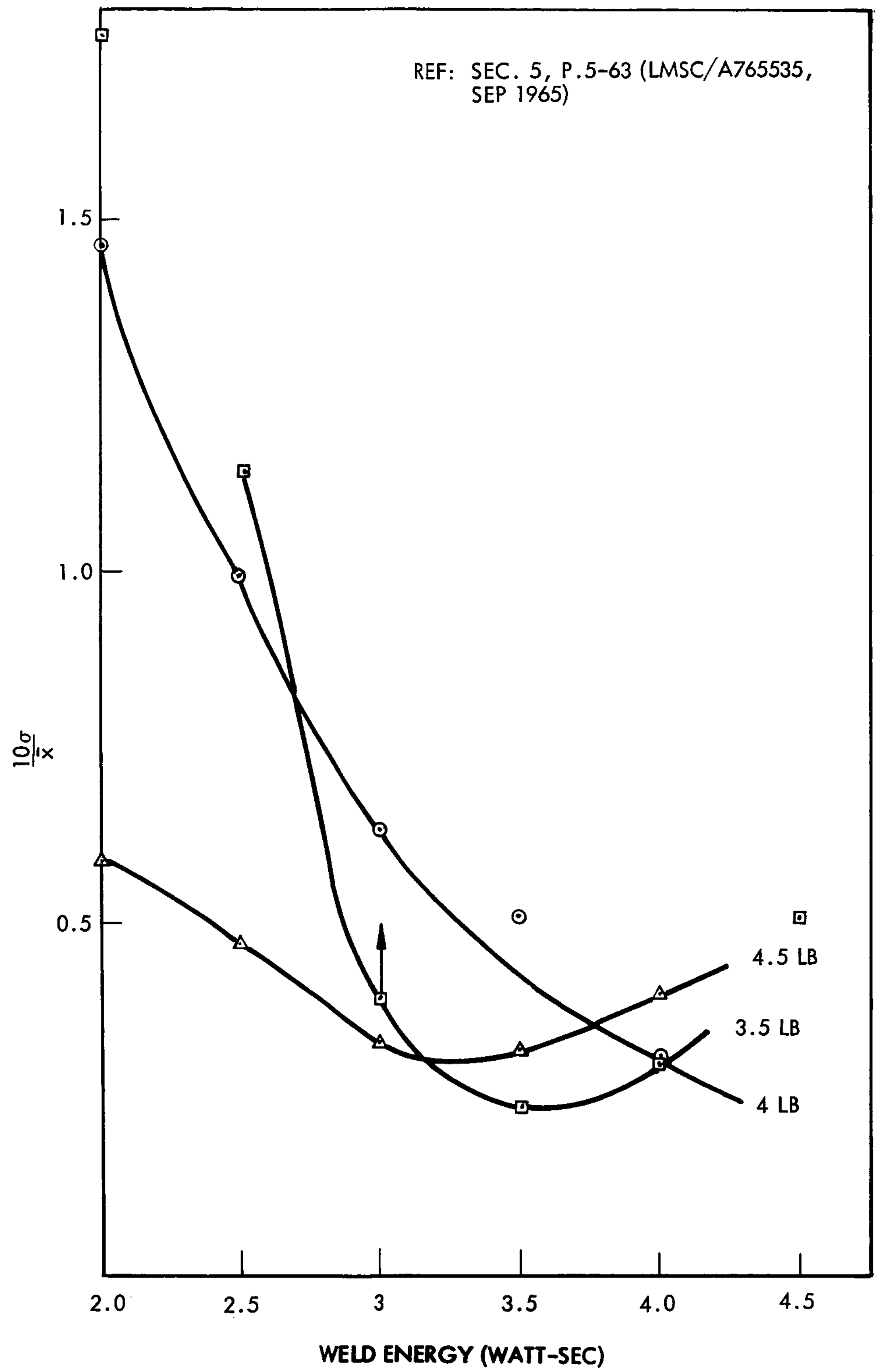


Fig. 1-9 Weld Energy Used in Weld Schedule Development – 0.02-In. Nickel to 0.017-In. Kovar (SIPPICAN Welder)

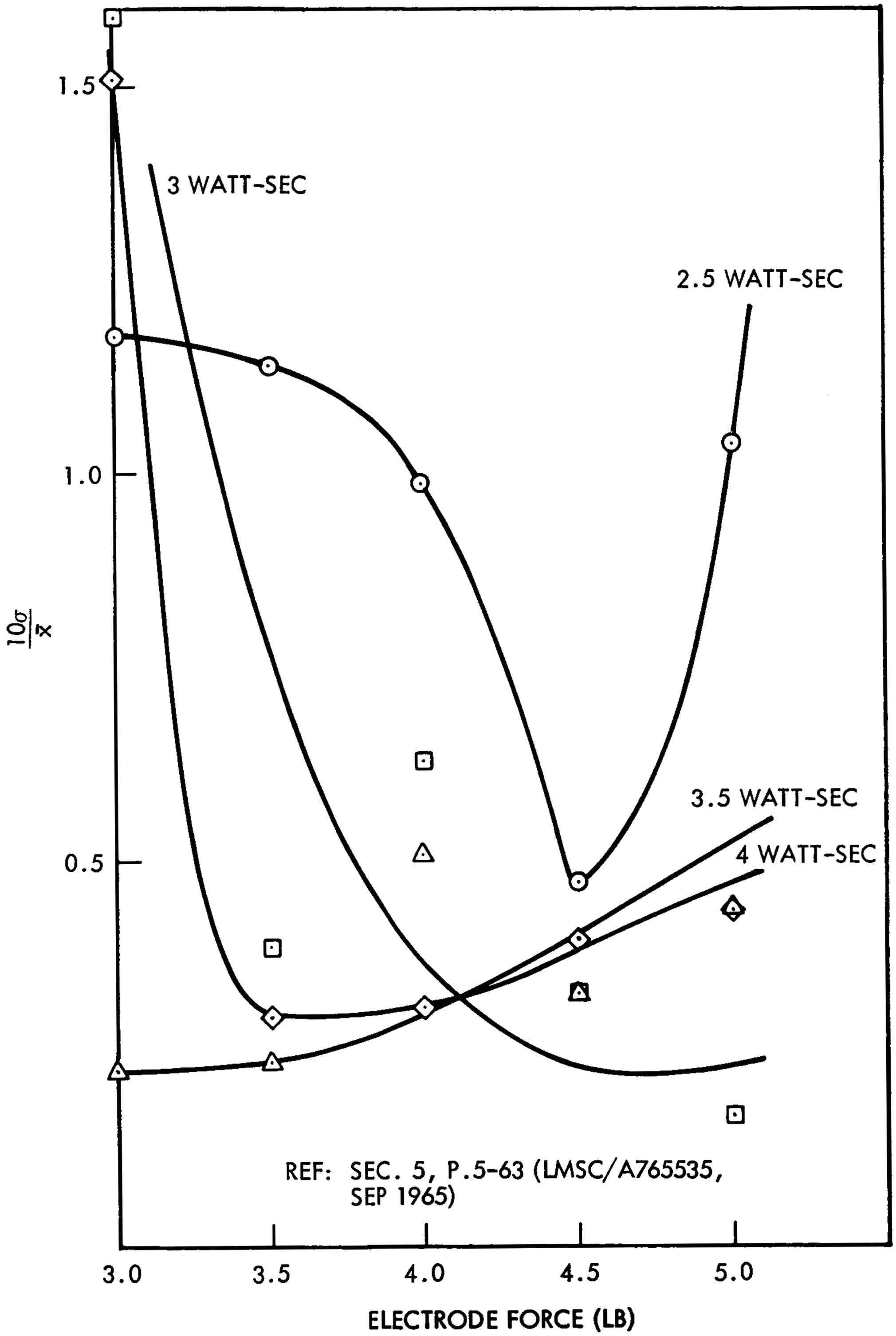


Fig. 1-10 Electrode Force Used in Weld Schedule Development – 0.020-In. Nickel to 0.017-In. Kovar (SIPPICAN Welder)

WELDER: RAYTHEON, MODEL 225C　　　DATE: 26 MAY 1965

MATERIAL: 0.025-IN. NICKEL WIRE TO 0.010 x 0.031-IN. NICKEL RIBBON

ELECTRODE PRESSURE (LB)	12	15	18	21	24	27
14.0	$\bar{x}$ = 14.57 σ = 4.30 $\frac{10\sigma}{\bar{x}}$ = 2.95	$\bar{x}$ = 20.35 σ = 0.38 $\frac{10\sigma}{\bar{x}}$ = 0.19	$\bar{x}$ = 20.71 σ = 0.57 $\frac{10\sigma}{\bar{x}}$ = 0.28	$\bar{x}$ = 21.21 σ = 0.27 $\frac{10\sigma}{\bar{x}}$ = 0.13	$\bar{x}$ = 21.35 σ = 0.63 $\frac{10\sigma}{\bar{x}}$ = 0.29	$\bar{x}$ = 22.07 σ = 0.34 $\frac{10\sigma}{\bar{x}}$ = 0.15
12.0	$\bar{x}$ = 18.64 σ = 1.55 $\frac{10\sigma}{\bar{x}}$ = 0.83	$\bar{x}$ = 20.57 σ = 0.61 $\frac{10\sigma}{\bar{x}}$ = 0.30	$\bar{x}$ = 21.50 σ = 0.29 $\frac{10\sigma}{\bar{x}}$ = 0.13	$\bar{x}$ = 21.00 σ = 0.50 $\frac{10\sigma}{\bar{x}}$ = 0.24	$\bar{x}$ = 21.71 σ = 0.27 $\frac{10\sigma}{\bar{x}}$ = 0.12	$\bar{x}$ = 22.28 σ = 0.70 $\frac{10\sigma}{\bar{x}}$ = 0.31
10.0	$\bar{x}$ = 18.07 σ = 2.26 $\frac{10\sigma}{\bar{x}}$ = 1.25	$\bar{x}$ = 20.21 σ = 0.49 $\frac{10\sigma}{\bar{x}}$ = 0.24	$\bar{x}$ = 21.00 σ = 0.41 $\frac{10\sigma}{\bar{x}}$ = 0.19	$\bar{x}$ = 21.00 σ = 0.71 $\frac{10\sigma}{\bar{x}}$ = 0.34	$\bar{x}$ = 21.79 σ = 0.49 $\frac{10\sigma}{\bar{x}}$ = 0.22	$\bar{x}$ = 22.57 σ = 0.19 $\frac{10\sigma}{\bar{x}}$ = 0.08
8.0	$\bar{x}$ = 19.71 σ = 0.70 $\frac{10\sigma}{\bar{x}}$ = 0.36	$\bar{x}$ = 20.86 σ = 0.47 $\frac{10\sigma}{\bar{x}}$ = 0.17	$\bar{x}$ = 20.71 σ = 0.39 $\frac{10\sigma}{\bar{x}}$ = 0.19	$\bar{x}$ = 21.57 σ = 0.46 $\frac{10\sigma}{\bar{x}}$ = 0.21	$\bar{x}$ = 22.21 σ = 0.27 $\frac{10\sigma}{\bar{x}}$ = 0.12	$\bar{x}$ = 22.57 σ = 0.46 $\frac{10\sigma}{\bar{x}}$ = 0.20
6.0	$\bar{x}$ = 17.14 σ = 1.72 $\frac{10\sigma}{\bar{x}}$ = 1.0	$\bar{x}$ = 21.07 σ = 0.53 $\frac{10\sigma}{\bar{x}}$ = 0.25	$\bar{x}$ = 21.35 σ = 0.38 $\frac{10\sigma}{\bar{x}}$ = 0.18	$\bar{x}$ = 21.71 σ = 0.27 $\frac{10\sigma}{\bar{x}}$ = 0.12	$\bar{x}$ = 21.71 σ = 0.64 $\frac{10\sigma}{\bar{x}}$ = 0.29	$\bar{x}$ = 21.57 σ = 0.53 $\frac{10\sigma}{\bar{x}}$ = 0.24

WELD ENERGY (WATT-SEC)

$\bar{x}$ Average pull strength
σ Standard deviation

Fig. 1-11 Preliminary Weld Schedule Development Data — 0.025-In. Nickel Wire to 0.010 × 0.031-In. Nickel Ribbon (RAYTHEON Welder)

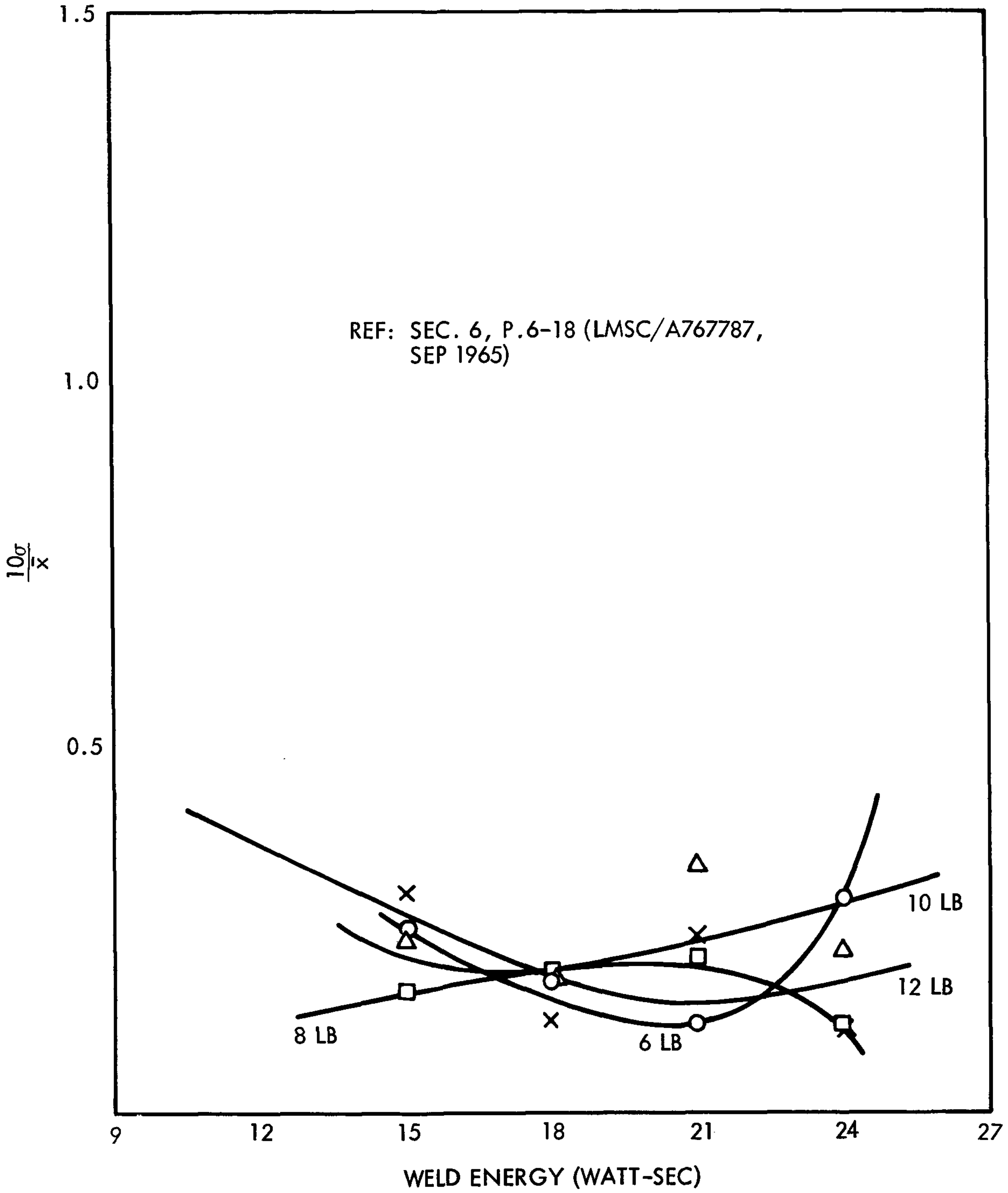


Fig. 1-12 Weld Energy Used in Weld Schedule Development – 0.025-In. Nickel Wire to 0.010 × 0.031-In. Nickel Ribbon (RAYTHEON Welder)

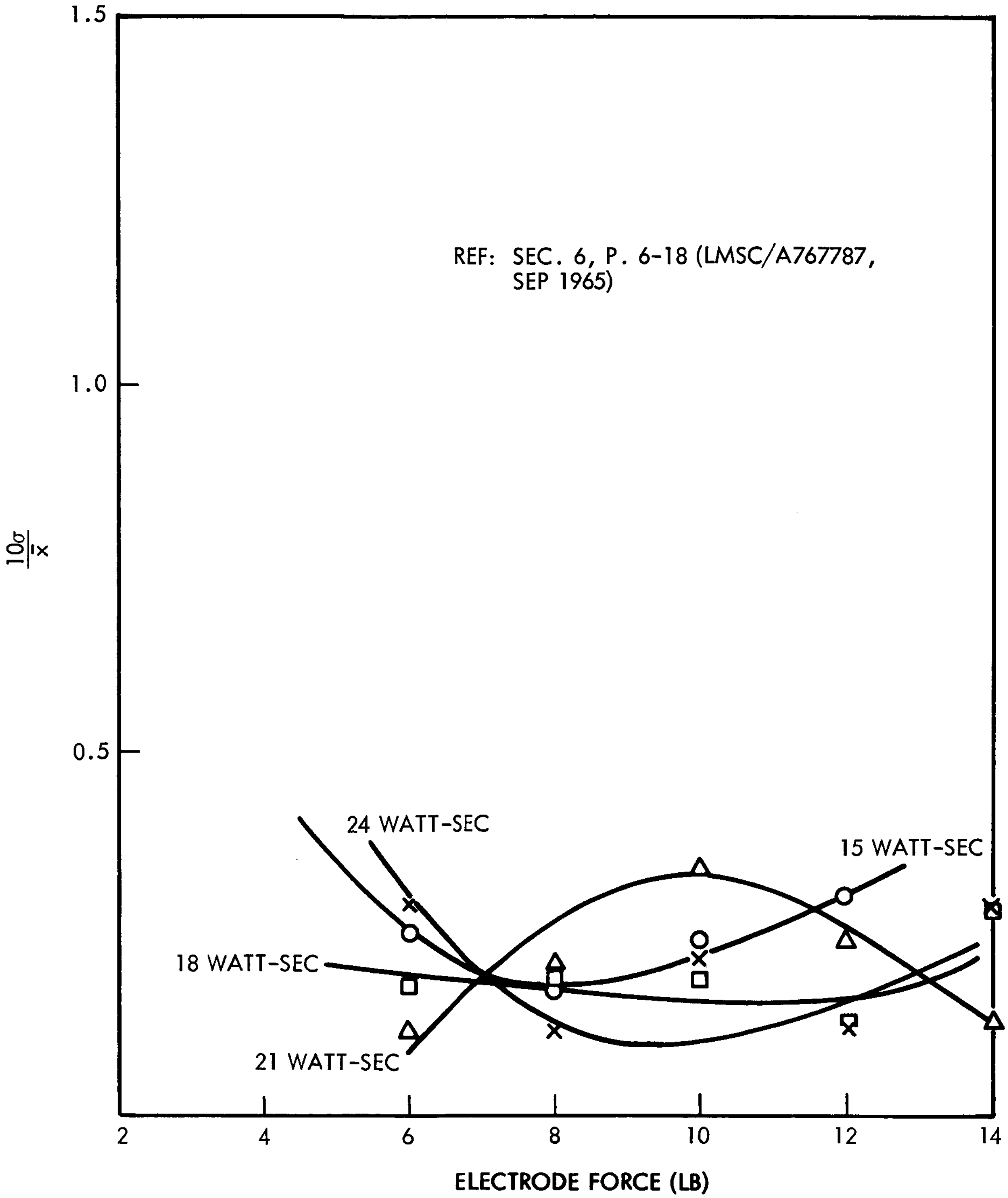


Fig. 1-13 Electrode Force Used in Weld Schedule Development – 0.025-In. Nickel Wire to 0.010 × 0.031-In. Nickel Ribbon (RAYTHEON Welder)

Figure 1-11 clearly indicates that a 24 watt-sec weld energy setting is on the high side and will result in more melting than is desirable for an optimum weld.

At this point, it should be emphasized that using an iso-strength diagram based upon pull strength of the weld alone is both a weak and often insensitive method of selecting a starting point upon which to base a weld schedule. Consideration of the standard deviation σ in addition to the pull strengths, as exemplified in the technique of minimizing the $\frac{10\sigma}{\bar{x}}$ parameter, appears to constitute a more effective tool for deriving a good starting point. In most cases, without going through formal plotting (like that shown in Figures 1-9, 1-10, 1-12, and 1-13), strength values combined with standard deviation values make possible a minimum of selections for preliminary metallurgical testing prior to arriving at a weld schedule for thorough investigation.

1.5.2 PARALLEL-GAP WELDING

LMSC gap-welding operations are not yet an established production process. Standards have not therefore been officially established for machine qualification and weld certification. The gap weld quality for this study was evaluated on the basis of the following characteristics:

- Mechanical strength of the weld (0-deg and 30-deg angle pull)
- Electrode embedment (less than 50 percent of the trace width)
- Adequacy of the metallurgical bond
- Weld heat effects on the trace substrate

A great deal remains to be done in determining the weld pulse characteristics for a particular lead-trace combination which will not only result in good mechanical strength but also provide optimum ductility in the heat-affected zone. Where a wide range of pulse characteristics is available, as in the GENERAL ELECTRIC Square-Pulse Bonder, a complete exploration of the multivariable field may require application of controlled-experiment mathematical techniques.

The following steps were performed to derive a weld schedule for gap welding leads to a particular trace:

- Each weld was examined microscopically at approximately 30X during preliminary testing.
- Weld strengths at both 0 deg and 30 deg angles were determined and correlated with the microscopic observations.
- When failures occurred in the weld (i.e., when the weld zone itself pulled apart), the nature of the separating interfaces was carefully examined. A failure in the weld between lead and trace was considered uniquely different from a failure between trace and substrate. In the former case, an increase in pulse amplitude effected, in the main, an increase in weld strength and quality. In the case of the latter, the approach to obtaining a better weld usually involved achieving a change in the time-temperature pattern. This was particularly true if the substrate was sensitive to heat shock; a longer, more gradual approach to the temperature was required for successful welding.
- Based upon the foregoing observations and examinations, machine settings were selected for a 50-specimen weld test.

1.6 CERTIFICATION OF WELD SCHEDULES

LMSC certification of a weld schedule for joining a particular material combination, using a particular welding machine, consisted of assuring that weld specimens met the following requirements.

1.6.1 VISUAL

Using a magnification of 10 to 15X, all welds were visually examined to verify that they were free of external voids, cracks, and tip pickup. If any specimen failed this visual examination, certification was not granted, and additional development of the weld schedule was required.

1.6.2 PULL STRENGTH

A weld quality coefficient of 50 percent or greater was required, based upon pull strengths obtained by the method shown in Figure 1-14. Twenty test specimens each for the four corner points, and 40 for the center point were required for this pull testing.

The weld quality coefficient Q is defined as the ratio of the average weld strength minus five times the standard deviation to the strength of the weaker parent material, expressed as a percentage, i.e.,

$$Q = \frac{\bar{x} - 5\sigma}{y} \times 100$$

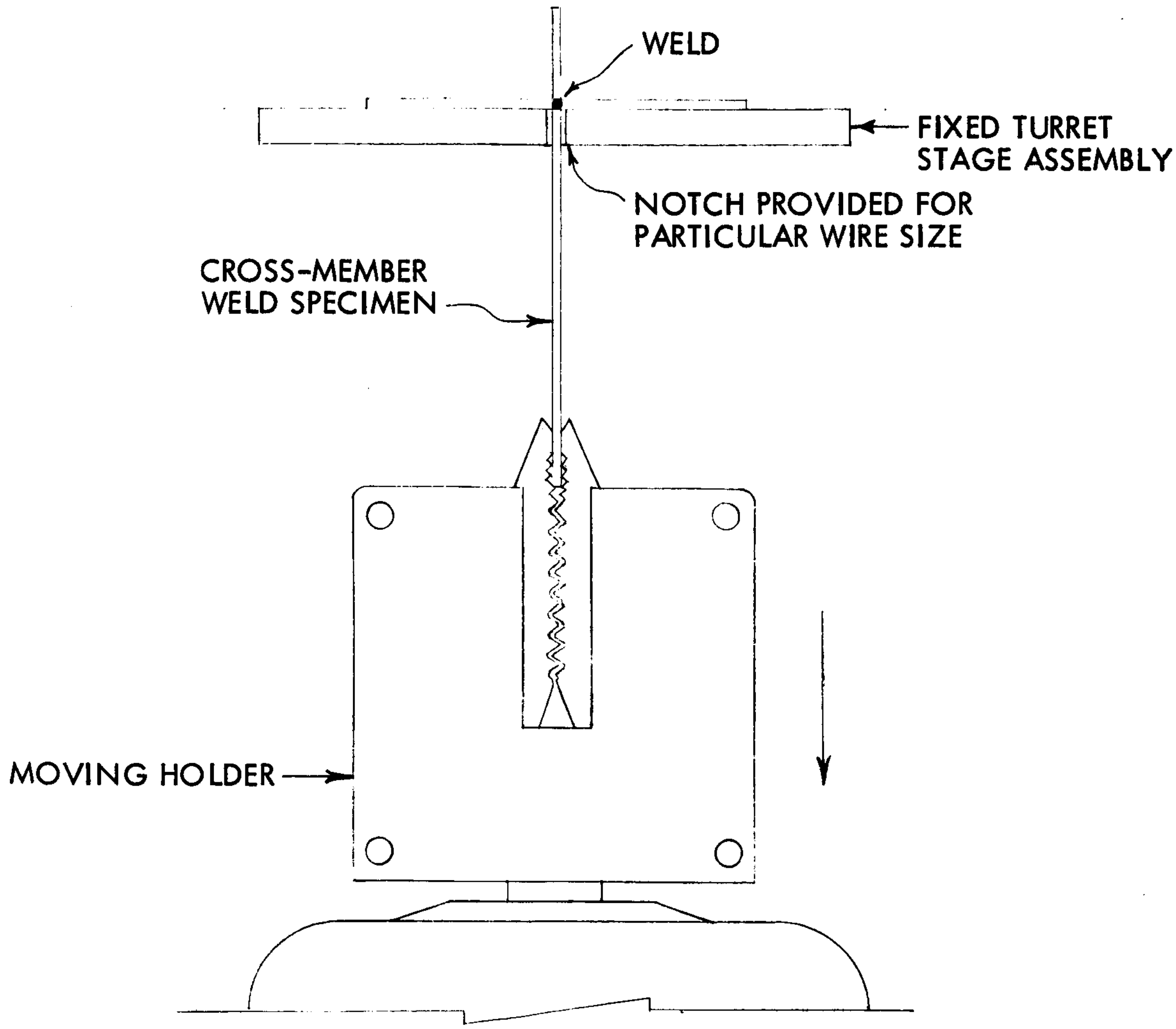


Fig. 1-14 Pull Testing Method

where

$\bar{x}$ = average of individual weld strengths

σ = standard deviation

y = minimum strength of the weaker member of the material combination (lb)

1.6.3 METALLURGICAL

Metallurgical examinations were made on two representative specimens for each corner point and the center point. One specimen was sectioned longitudinally, and one transversely. These sectioned specimens were then polished, etched, and examined at a minimum of 100X magnification to determine their conformance to the following criteria:

- Metallurgical bonding had to exist across 85 percent of the welded interface.
- Maximum dimensions of voids, which may consist of holes in the interface or in the fusion zone, could not exceed 15 percent of the interface length and could not extend to within 10 percent of either end of the interface. More than one void was permissible only if the evaluation of the maximum dimensions did not exceed 15 percent of the interface length.
- Cracks or fissures in or adjacent to the weld zone were not permitted.
- The depth of recrystallized melt zone into either parent metal, commonly referred to as penetration, could not be greater than 50 percent of the smallest component. Further, there could be no evidence of base metal melting at the outer surface of any component member.
- Maximum dimension of expulsion (expelled metal deposited alongside the joint during the weld cycle) could not be greater than 50 percent of the

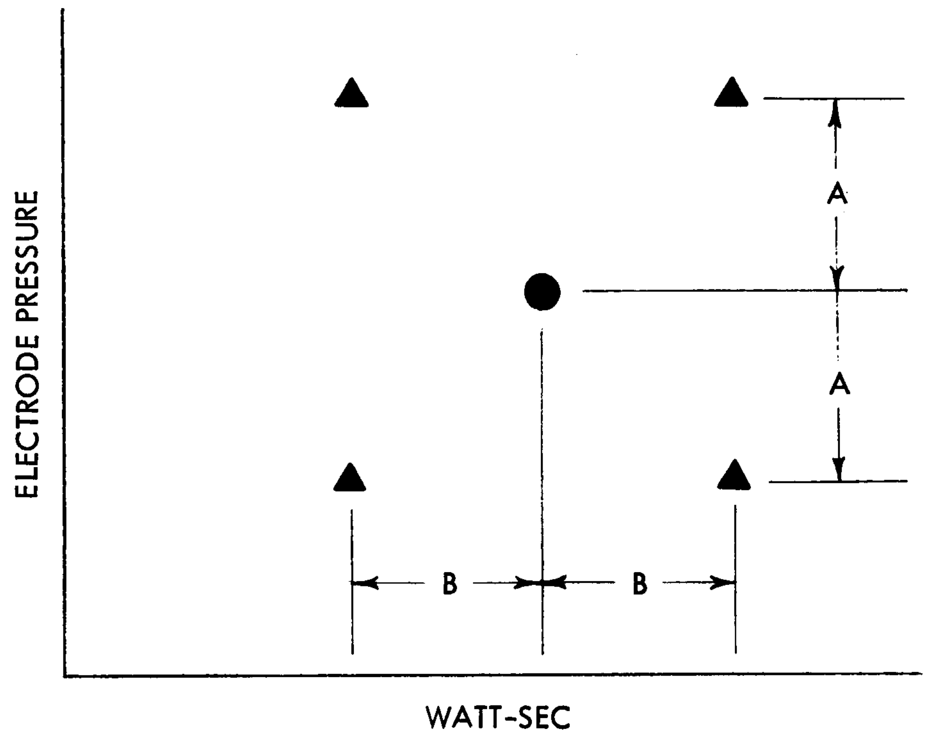
largest dimension of the smallest component member, and had to be solidly adhered to the parent material.

- Surface indentation or depression on the exterior surface of the base metal caused by electrode pressure could not exceed 20 percent of the total original component dimension.
- Notches at either end of the interface or on the surface of either component were not permitted.
- Tip pickup, which can result in a hole through one or both of the welded components due to metallic bonding of components to electrodes, was not permitted.

1.6.4 CERTIFICATION STEPS

Optimum welding parameters of electrode pressure, weld energy, electrode materials, pulse length (if applicable), etc., were first determined for a particular combination being joined, as previously described in Subsection 1.5. The following test steps were then performed to obtain LMSC certification:

- Step 1. Preliminary corner point locations, based upon electrode pressure and weld energy, were developed as shown in Figure 1-15. A minimum of 100 welds (25 representative welds for each point of the box) were used to verify these corner point locations. All weld specimens had to meet the requirements of Subsections 1.6.1 through 1.6.3.
- Step 2. Verification of the center point location required a minimum of 45 weld test specimens. As in Step 1, all weld specimens had to meet the requirements of Subsections 1.6.1 through 1.6.3. The pull-test results for 40 weld specimens were used to calculate the standard deviation σ and weld quality coefficient Q. (See Subsections 1.5.1 and 1.6.2.)



<u>DISTANCE A</u> – MINIMUM MUST BE 10 PERCENT OF PRODUCTION SETTING

<u>DISTANCE B</u> – MINIMUM MUST BE 10 PERCENT OF PRODUCTION SETTING EXCEPT FOR NICKEL ROUND WIRE TO NICKEL ROUND WIRE. THIS COMBINATION REQUIRES A MINIMUM DISTANCE OF 15 PERCENT. HOWEVER, CERTIFICATIONS FOR THIS STUDY WERE NOT FOR PRODUCTION REQUIREMENTS; THEREFORE ALL B DISTANCES WERE HELD AT 10 PERCENT.

Fig. 1-15 Box Point Location Requirements

1.7 SUMMARY AND CONCLUSIONS

Results from the study of each welder are presented in the individual report sections of this contract series. This summary compares the four cross-wire welders and three parallel-gap welders through use of an overall performance survey.

The evaluation criteria are specified in Section I. B. (1) through (8) of Appendix A of NASA Contract NAS 8-11488. These criteria are as follows:

- Ability to produce consistently good welds
- Versatility with reference to material variations
- Accuracy of machine and simplicity of controls
- Initial and operational cost
- Envelope size and location control
- Design and circuitry
- General reliability of operation
- Operator skill levels required

The findings presented below are based on a limited operation which averaged 3 months per machine. A longer operational period may lead to slightly different conclusions.

1.7.1 CROSS-WIRE WELDING MACHINES

The evaluation of the four cross-wire welders is presented in Table 1-8. A study of this table will show that none of the four is superior to the others on all counts; for example, the RAYTHEON welder (Model 225C/OB) was rated highest in versatility

WELDING MACHINE (in order of study)		
	Ability to Produce Consistently Good Welds	Versatility With Reference to Material Variations
SIPPICAN Model 4/214 DR	LOW Lowest of four machines tested	LOW Due to single short pulse.
RAYTHEON Model 225C/OB	GOOD About same as WELDMATIC 1-059-02	HIGH Highest due to wide range of pulse lengths available
WELDMATIC Model 1-059-02/2-032-03	SATISFACTORY Ability to produce consistent welds depends on suitability of single pulse	LOW Like SIPPICAN, due to single short pulse
WELDMATIC Model 1-065-02/2-032-03	HIGH Highest of four machines tested	MEDIUM Versatility improved by virtue of longer weld pulse available

EVALUATION CRITERIA

Machine Accuracy and Control Simplicity	Cost – Initial and Operating	Envelope Size and Location Control
GOOD Pressure adjustment mechanism good Calibration feature excellent	POOR Considering machine versatility and performance	EXCELLENT Compact, neat in appearance, and convenient to operate
SATISFACTORY For simplicity and accuracy Basic redesign of controls needed	EXCELLENT More favorable than any of machines tested, based on general reliability and versatility	POOR Equipment difficult to assemble for efficient and space saving operation
EXCELLENT	POOR Considering machine versatility	EXCELLENT
HIGH Highest of four machines tested; adjustment of pulse length easily made	AVERAGE Based on pulse characteristics, cost may be considered high	HIGH Highest of the four machines tested; easily installed and all controls convenient to operator

V

Design and Circuitry	General Reliability of Operation	Operator Skill Levels Required
Considered poor design because of single short pulse	LOW Lowest of four machines tested	MEDIUM Pressure calibration somewhat difficult. Electrode alignment relatively difficult
EXCELLENT Electrically excellent due to range of pulse lengths Mechanical operation could be improved	GOOD Main deterrent is head, which is not considered as reliable as WELDMATIC 2-032 head	LOW Lowest of four machines tested
Considered poor design because of single short pulse	GOOD When welding materials for which single short pulse is applicable	HIGH Very similar to WELDMATIC, Model 1-065
Pulse characteristics poorly designed; standard and normal pulse not significantly different and long pulse not sufficiently long	EXCELLENT	HIGH Highest of four machines tested

3

Table 1-8 Evaluation of Cross-Wire Welders with reference to material variations; it rated low in envelope size and location control because of its separate transformer, large control box, and separate pneumatic control. In addition, LMSC found confusing the use by RAYTHEON of letters A, B, and C to designate the capacitor bank size and A, B, C, and D to designate the transformer primary and secondary switching arrangements. Further, the OB head pneumatic control was found to require very high operator skill. With reference to initial and operating cost, however, the RAYTHEON welder was rated highest among the four machines studied.

LMSC arrived at the following overall rating for these four cross-wire welding machines:

- Highest – RAYTHEON, Model 225C/OB
- Second – WELDMATIC, Model 1-065-02/2-032-03
- Third – WELDMATIC, Model 1-059-02/2-032-03
- Lowest – SIPPICAN, Model 4/214DR

1.7.2 PARALLEL-GAP WELDERS

Evaluation results for the three parallel-gap welders are presented in Table 1-9.

Each machine operates on a different design principle:

- SCR-controlled capacitor discharge welding with 1 to 20 pulses per weld, interspersed with controlled cooling pulses (GENERAL ELECTRIC)
- Storage-battery-powered combination of three consecutive d-c pulses (WELDMATIC)
- Ac-operated sine wave pulses with controlled up-and-down slope (WELTEK)

WELDING MACHINE (in order of study)	Ability to Produce Consistently Good Welds	Versatility With Reference to Material Variations
GENERAL ELECTRIC SQUARE-PULSE BONDER	HIGH Highest of three machines tested Electrode easily dressed and cleaned; no flexing under pressure	HIGH Highest of three machines tested Versatility due to wide control over heating pulse(s)
WELDMATIC Model 1090C	GOOD When confined to the limited range of fine lead to thin films for which designed	VERY POOR Suited only for bonding fine leads to thin films
WELTEK Model AC-5/410D	LOW Lowest of three machines tested Electrode adjustment difficult; very sensitive to electrode contamination	GOOD Appeared to perform better when welding leads to thick traces

EVALUATION CRITERIA		
Machine Accuracy and Control Simplicity	Cost – Initial and Operating	Envelope Size and Location Control
HIGH Highest of three machines tested All controls logically arranged and easily understood	MEDIUM Initial cost high and operating costs appear high	HIGH Highest of three machines tested All controls easily accessible Power source and welding head both in one unit
GOOD When operated within its limited range of thin film areas	LOW Lowest of three machines tested Initial cost very high Electrodes expensive	LOW Lowest of three machines tested Assembly awkward; controls not conveniently accessible to operator
LOW Lowest of three machines tested Controls overly complicated in areas where machine operated best	GOOD to EXCELLENT Cost considered very reasonable for overall capability of unit	GOOD Controls convenient to the operator

Design and Circuitry	General Reliability of Operation	Operator Skill Levels Required
HIGH Output of controlled d-c pulses represents advanced development in microwelding equipment	HIGH Highest of three machines tested	HIGH Highest of three machines tested Optimum weld settings easily determined.
LOW Lowest of three machine tested Weld power controls use reed switches not considered as reliable as d-c types	LOW Lowest of three machines tested	FAIR When used in the areas of thin film welding for which designed
FAIR Pulse lengths appeared stable; up-slope and down-slope outputs easily regulated	MEDIUM Operation generally trouble free Higher rating cannot be given because of difficulty in aligning electrodes	LOW Lowest of three machines tested Optimum welding conditions difficult to establish

3

Table 1-9 Evaluation of Gap Welders

Electrode design and construction were also different for all three machines. (See Subsection 1.4.2.)

During operations utilizing these machines, it was demonstrated that alternate application of heating and cooling intervals resulted in high quality welds. This result occurs because the welding temperature can thus be reached by adding small, controlled, increments of heat in steps, thereby preventing the dangerous overheating which frequently causes severe stresses in the materials bonded or in the substrate. Application of the multi-sine wave pulse also allows careful temperature control, and thus prevents overheating. However, use of the preheat, weld-heat, and post-heat arrangement proved less successful because the heat quantities were too large to provide this required gradual heating.

The reed switches used by WELDMATIC to control weld current flow were alleged (by the vendor) to have been the source of some of the initial operating difficulties with this equipment. The electric timing controls used on both the GENERAL ELECTRIC and WELTEK welders are considered by LMSC to be more reliable.

The initial investment required for the three parallel-gap machines studied varies over a wide range as follows:

- GENERAL ELECTRIC Square-Pulse Bonder $4,950
- WELDMATIC, Model 1090C $5,450
- WELLS WELTEK, Model AC-5/410D $2,142

However, technical performance should be the only criterion used for rating. On the basis of this performance yardstick, LMSC therefore rates the machines as follows:

- Highest – GENERAL ELECTRIC Square-Pulse Bonder
- Second – WELLS WELTEK Microbonder, Model AC-5/410D
- Third – WELDMATIC Microbonder, Model 1090C

These ratings are based on limited periods of operating time, which were far too short to gain adequate information on such aspects as repairability, maintenance, and long-term performance.

1.8 RECOMMENDATIONS

A study of the type performed under this contract is essentially limited to the state-of-the-art as it exists at the time the contract is awarded. However, the fast-moving development of new microwelding equipment has since made several machines commercially available which are claimed to possess superior properties to some of those covered by this investigation. It is therefore recommended that the results of this study of resistance microwelding equipment be brought up to the state of current technology by investigating the performance of the following microwelding machines:

- WELDMATIC Unibonder, Model 1124/1125
- HUGHES Microbonder, Model MCW/EL/IL
- SIPPICAN Microwelder, Model CP-PC
- SCIAKY Welder, Model SPO-0-59-2-3A

The SCIAKY welder is a relatively high-priced piece of equipment which has never, to LMSC knowledge, been fully evaluated for electronic use. It would appear necessary to subject this machine to an extended study to determine its accuracy, repeatability, and reliability of performance.

The other three microwelders recommended for investigation are improvements or complete redesigns of earlier models and should thus be capable of producing better results than the models investigated during the study.

This contract work was specifically limited to electrically operated resistance microwelding equipment suitable for either cross-wire or parallel-gap welding. A study covering the microbonding state-of-the-art, as such, would not be complete without including ultrasonic welding, thermocompression bonding, electron-beam welding, and laser welding. Consequently, it is further recommended that studies be made of the following equipment:

- Ultrasonic Bonder
  - AXION, Model M, or
  - SONOBOND, Model MP-20-L
- Thermocompression Bonder
  - AXION, Model MT, or
  - KULICKE & SOFFA, Model 420, 421, or 444
- Laser Welder
  - LEAR-SIEGLER, Model LW-212, or
  - TECHNICAL RESEARCH, Model V-2902
- Electron-Beam Welder
  - HAMILTON-ZEISS,
  - ALLOYD ELECTRONICS CORPORATION, or
  - ELECTRON BEAM CORPORATION

1.9 REFERENCES

1-1. Lockheed Missiles & Space Company, Study of Welding Equipment for Electronic Components, Sections 2 through 8, Various Dates, July through Dec 1965

1-2. -----, Section 2, Figure 2-4, p. 2-9, LMSC/A775904, Dec 1965

1-3. -----, Section 3, Figure 3-1-2, p. 3-5, LMSC/A759101, Jul 1965

1-4. -----, Section 3, p. 3-6, LMSC/A759101, Jul 1965

1-5. -----, Section 4, Figure 4-1-3, p. 4-6, LMSC/A762532, Aug 1965

1-6. -----, Section 5, p. 5-63, LMSC/A765535, Sep 1965

1-7. -----, Section 6, p. 6-18, LMSC/A767787, Sep 1965

1-8. -----, Section 5, p. 5-64 (photomicrograph), LMSC/A765535, Sep 1965

1-9. -----, Section 6, p. 6-18, LMSC/A767787, Sep 1965